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Article

Predictive Maintenance of Hydraulic Lifts through Lubricating Oil Analysis

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Abstract: This article examines the possibility of measuring lift maintenance through analysis of used hydraulic oil. Hydraulic oils have proved to be a reliable indicator for the maintenance performed on elevators. It has also been proved that the end users or the maintenance personnel do not always conform to the instructions of the elevators' hydraulic machine manufacturer. Furthermore, by examining the proportion of the metals, an estimation of the corrosion and the wear resistance of the joined moving parts can be observed. Additionally, the presence of chlorine and calcium in hydraulic oils demonstrates their function in a highly corrosive environment.

Keywords: hydraulic oil; elevator; lift engine; metals; viscosity; total acid number

1. Introduction

Hydraulic oil plays a key role in hydraulic lifting equipment and in hydraulic machines. Hydraulic systems and their equipment rely upon the use of pressurized liquid in order to transmit power. This transmission of power in hydraulic elevators is mainly used for performing the lifting work. Hydraulic fluids are classified in various ways. One of these is based upon the major ingredient—the base fluid. Based on this classification, the two major hydraulic fluid class descriptions are:

- mineral oils and
- synthetics [1].

Basically, the Hydraulic fluids are classified based upon their viscosity grades [2,3]. The substances of the oils depend upon the application type in which the oil is going to be used. The same chemistry can be used for mobile and industrial hydraulic oils since many manufacturers build both types of hydraulic systems [4].

Working lubricating oils in machinery consist of complex mixtures of hydrocarbons having molar masses in the range 250–1,000. Their formulation consists of mixing, until homogeneity, a combination of basic oils and additives in defined proportions in order to provide compositions appropriate to the use for which the lubricant is intended [5].

Its main purpose is to guide a moving part through smooth motion or rotation and simultaneously to reduce mechanical erosion [6]. Sometimes, it contributes to the cooling down of the mechanical components [7]. There are several brands of lubricating oil for hydraulic lifts. Each manufacturer has its own knowhow regarding blending mineral components with additives [8]. Based on the specifications data and the operating condition of the machines, suitable lubricating oil can be selected with respect to safety [9].

Studies on hydraulic motors have shown that optimizing friction in boundary lubrication can significantly improve hydraulic motor efficiency [10,11]. It is critically important to ensure efficient lubrication in order to avoid equipment failures. Failures in boundary-lubricated contacts are generally avoided or reduced by using suitable and efficient lubricating additives [12]. The quality of the lubricating oil is essential for the preservation of the action and the longevity of machines. During the use of hydraulic oils in engines and machines in general, contamination can occur. Those contaminants interfere directly with the viscosity of the oil, lowering its performance characteristics. These interferences can lead to mechanical waste and can cause irreversible damage to the mechanical equipment [13,14].

In order to assess the reliability and efficiency of the elevators, a maintenance program is a significant part of the overall elevator system. Safe and reliable operations are of paramount importance to the owners and the tenants as well as the visitors who travel throughout these installations daily [15]. The EU, realizing the necessity of the safe transportation with lifts, issued directive 95/16/EC of 29 June 1995, on the approximation of the laws of the Member States relating to lifts. This directive also includes the directive 98/37/EC relating to machinery. Currently, directive 98/37/EC has been replaced by directive 2006/42/EC which also amended the lifts directive [16]. Despite its importance, inspection of the Hydraulic oil quality which was used in the hydraulic elevators is not a subject of the maintenance program.

The behavior of the used hydraulic oil in three hydraulic elevators was investigated experimentally in this study. Through this experimental approach, the performance of the oil was measured and its oxidation was observed. Additionally, phosphorous, zinc, chlorine and calcium were measured in order to investigate the mechanical erosion of the elevators. Seven samples were analyzed based on well-established analytical methods. The sampling period was from October 2012 until May 2013.

2. Experimental Section

Three different elevators were selected in order to examine the hydraulic oil characteristics. The technical characteristics of these elevators are presented in Table 1. Seven samples from each elevator were collected from October 2012 to May 2013.

Table 1. Technical Characteristics of the examined elevators.

Characteristic	**Elevator**		
	I	II *	III
Levels (number)	2	3	3
Distance (m)	3	6	6
Valve Blain (m)	0.0381	0.0508	0.0381
Power of Engine (kW)	20	40	20
Static pressure (bar)	27	21	27
Maximum pressure (bar)	45	40	45
Relief pressure (bar)	57	51	57
Suggested Manufacture Viscosity	ISO VG 32	ISO VG 32	ISO VG 32

* The elevator has double strokes.

Elevators I and III have the same technical characteristics. The only differences are that Elevator III has one more level to cover and double the distance to travel. The traffic load is the same between these two lifts. The engine of Elevator II has double power compared to the previous two. Elevator II has to cover the same levels and distance as Elevator III but has less traffic load.

For each series of samples, nine characteristics were examined including Kinematic Viscosity at 40 °C, Kinematic Viscosity at 100 °C, Viscosity Index (VI), Total Acid Number (TAN), Sulfur (S), Phosphorous (P), Zinc (Zn), Chlorine (Cl) and Calcium (Ca) concentration. Kinematic Viscosity at 40 °C and Kinematic Viscosity at 100 °C were determined according to ASTM D445-12 [17]. Viscosity Index (VI) was determined according to ASTM D2270-10e1 [18]. The viscosity parameters examined by using CANNON Viscometers and TAMSON 4000 Viscosity baths [19]. TAN was determined according to ASTM D974-12 [20]. Sulfur (S), Phosphorous (P), Zinc (Zn), Chlorine (Cl) and Calcium (Ca) concentration was measured by QM Spectroquant Wavelength Dispresive X-Ray Fluorescence analyzer. Each value reported in this study is the average of three scans. The average and the standard deviation are also reported. Additionally, the analysis of the October 2012 sample was the base for commenting all the subsequent results.

3. Results and Discussion

In this study, viscosity, acidity and metals of hydraulic oil from three different elevators have been investigated. The results reveal that the hydraulic oils which were used do not correspond to the standard characteristics and this, probably, influences the machine's operational behavior. The influence of the properties examined in the performance of the hydraulic lifts is discussed in detail in the following sections.

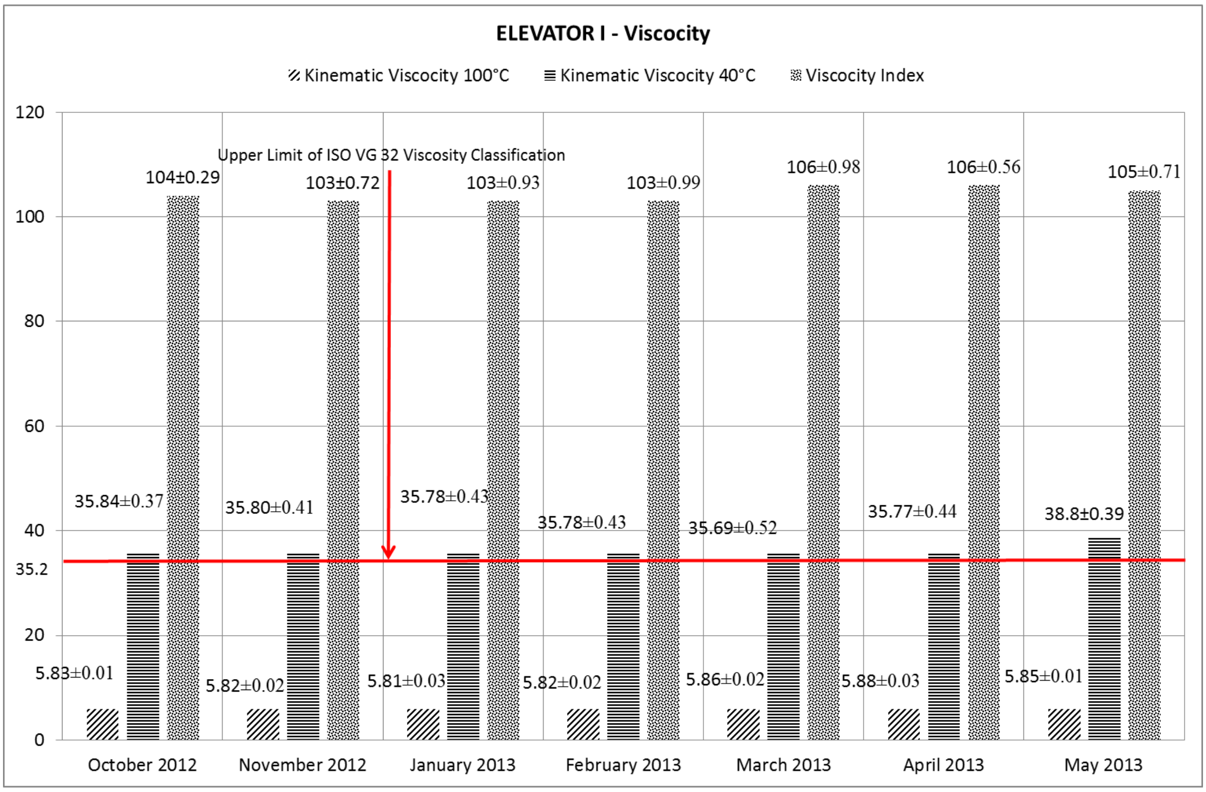
3.1. Viscosity

Viscosity is the single most important property of the hydraulic oil. The viscosity is a measure of hydraulic oil's resistance to gradual deformation by shear stress or tensile stress. According to ISO Viscosity Classification scale, the proposed ISO VG32 oil must have kinematic viscosity at 40 °C between 29.8 and 35.2 mm^2/s (cSt) [2]. In all three elevators, the kinematic viscosity of the working hydraulic oil is above the upper limit. This means that working oils comply with the specification.

If the viscosity of the working oil is higher than that proposed from the machine manufacturer then flow resistance will increase as the oil passes through the clearances in the hydraulic pump and valves. Additionally, the temperature will increase due to lack of lubrication. The lack of lubrication will result in a pressure drop in the system and the increment of the power consumption.

The changes of viscosity parameters for Elevator I are depicted in Figure 1. It is obvious that working oil's kinematic viscosity at 40 °C was outside the specification limits in all samples. It is noted that for the sample taken in May 2013 there is an increase of the value, meaning that the elevator is not operating well. This is one of the basic reasons to change the hydraulic oil in the elevator's hydraulic machine.

Figure 1. Viscosity in Elevator I.



Additionally the viscosity parameters for Elevator II are illustrated in Figure 2. All of the samples are above the upper limit. The kinematic viscosity at 40 °C has no significant variation between the samples. It worth noticing, that a 4-point variation in the Viscosity Index (VI) occurred between November 2012 and February 2013. The Viscosity Index expresses the performance of the oil or fluid to the temperature variations. This observation shows that a temperature variation took place.

The measurements of viscosity characteristics for the Elevator III are presented in Figure 3. The measurements of kinematic viscosity clearly indicate that the hydraulic oil is not ISO VG 32 grade, but ISO VG 46 grade. The Viscosity Index raised six points between October 2012 and November 2012 which reveals a temperature variation. From the maintenance book of the Elevator III, the breakdowns for the same period are presented in Table 2. Elevator I and Elevator II's maintenance books have not shown any breakdowns for the reported period.

Figure 2. Viscosity in Elevator II.

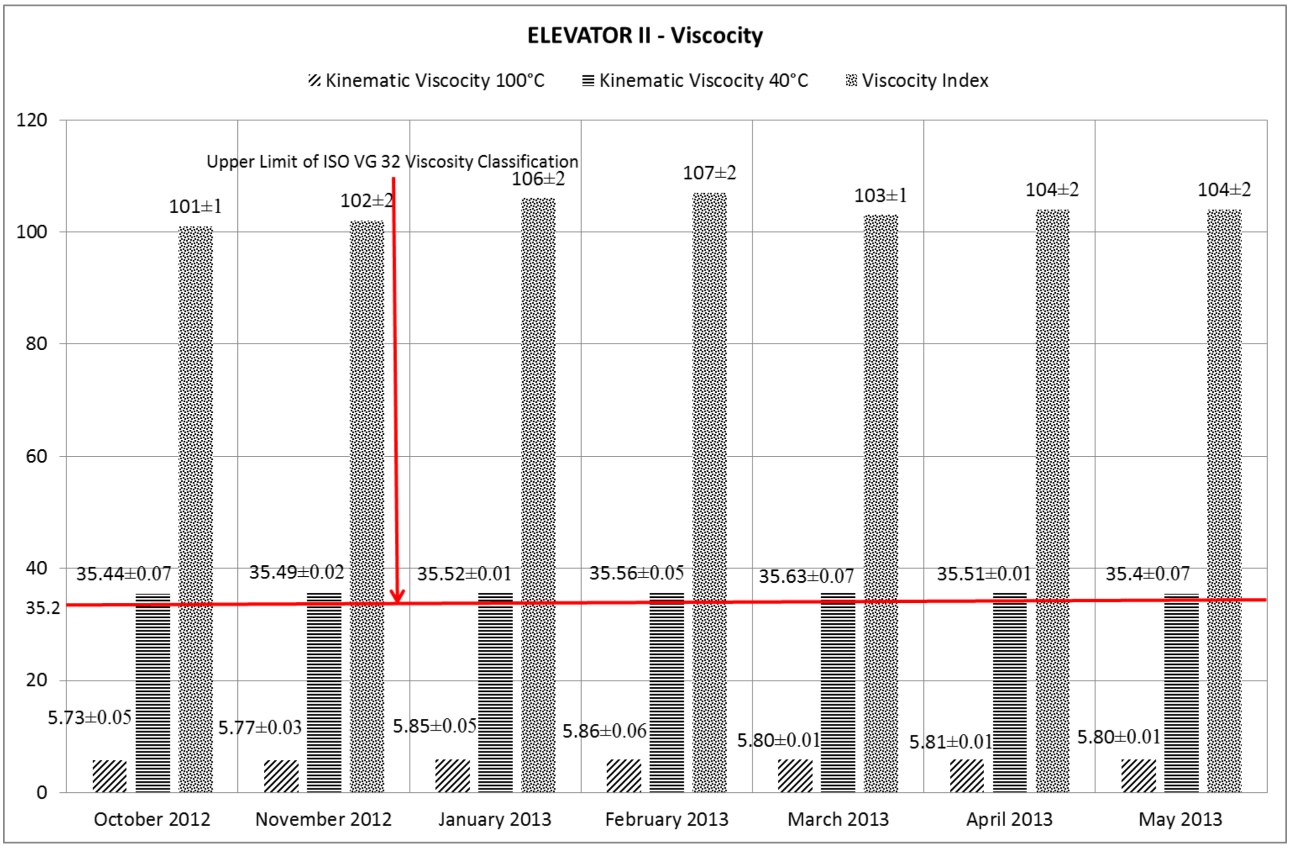


Figure 3. Viscosity in Elevator III.

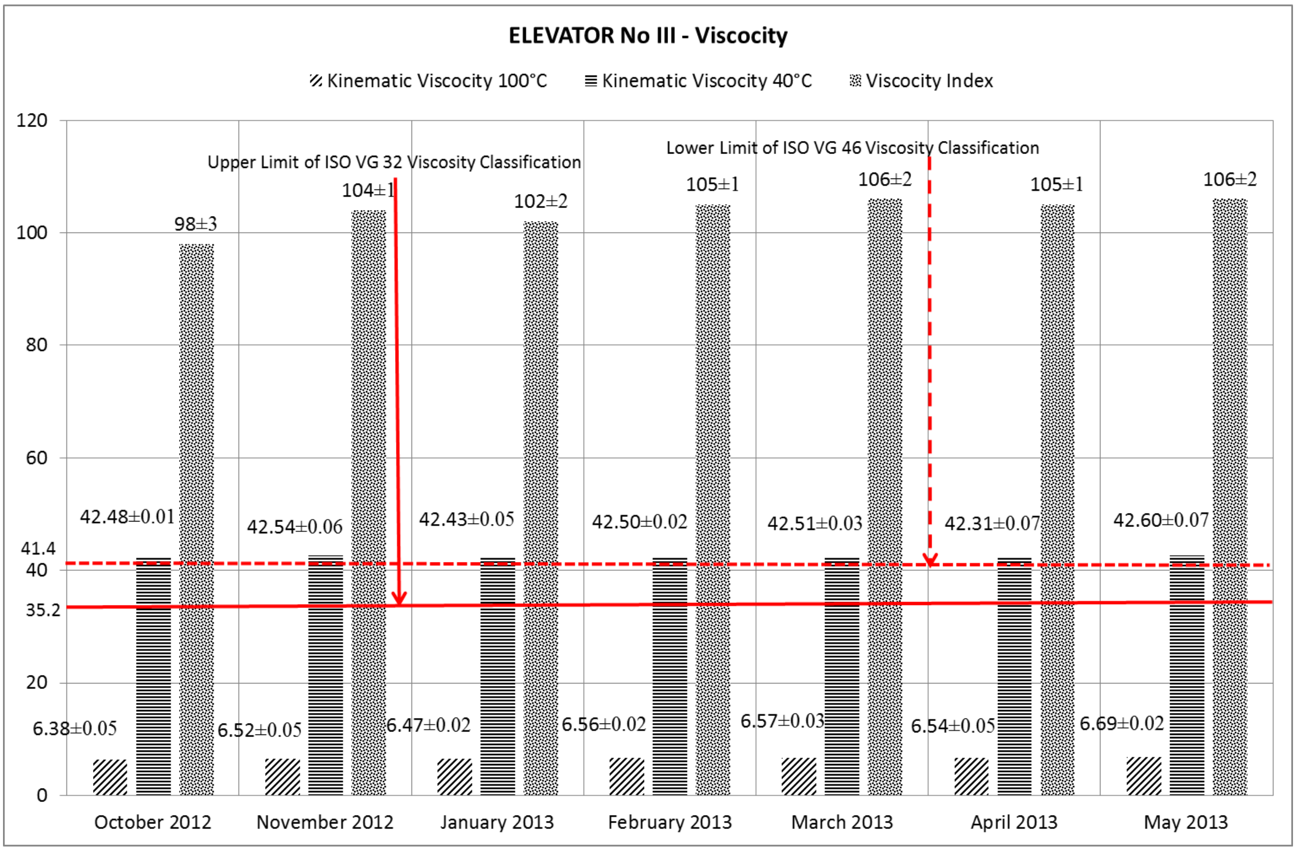


Table 2. The breakdowns of Elevator III.

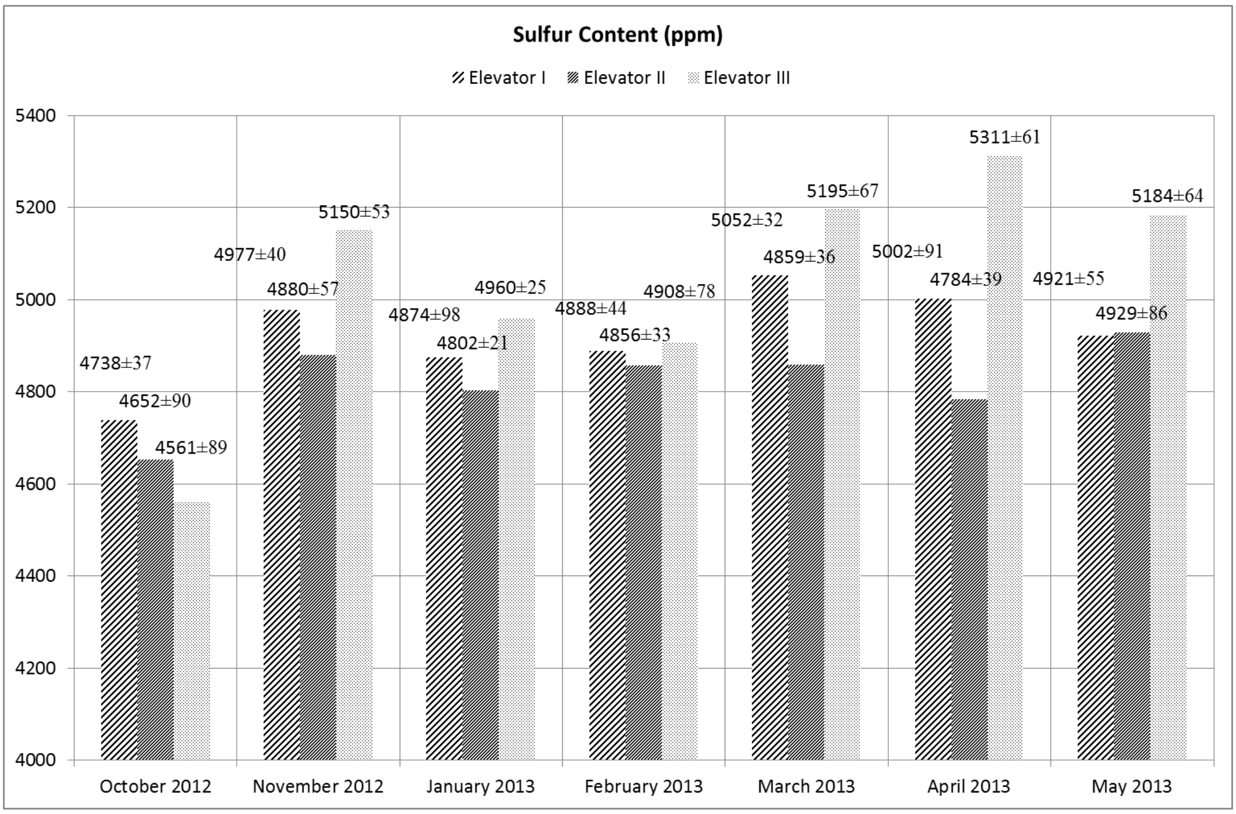
November 2012	January 2013	February 2013	March 2013	April 2013	May 2013
29/11 valves o-ring erosion	9/1 overheating	23/2 overheating	29/3 overheating	30/4 overheating	1/5 overheating
	13/1 overheating	24/2 overheating			12/5 overheating
	23/1 overheating				14/5 overheating
	26/1 overheating				

3.2. Sulfur

Sulfur in the base oils exists in the form of organo-sulfur compounds from the base stock. Additionally, sulfur-containing additives are often used in oils in order to formulate lubricants with improved oxidation stability, anti-wear and extreme pressure performance respectively. Oils with a high presence of sulfur have good oxidation stability.

In Figure 4, the sulfur concentration of the examined hydraulic oils for all the elevators is presented. From the sulfur concentration it is obvious when hydraulic oil is added to each elevator. More specifically, for Elevator I this occurred in November 2012 and March 2013. For Elevator II, oil was added in November 2012 and May 2013. For Elevator III hydraulic oil was added in November 2012, March 2103 and May 2013.

Figure 4. Sulfur concentration of Hydraulic Oils.



3.3. Total Acid Number (TAN)

Total Acid Number is an analytical test to determine the deterioration of hydraulic oils and lubricants. The more acidic the oil there is, the further its degradation has proceeded. As oils or hydraulic fluids breakdown, they generally form acidic byproducts that can be corrosive to metal components, accelerate wear, form deposits and increase viscosity. As a fluid degrades, the levels of corrosive acids increase, along with the danger of component failure. An increased TAN is a result of oxidation of the oil, perhaps caused by overheating, overextended oil service, or water and/or air contamination. Components within refrigeration systems are particularly susceptible to acid attack. This can occur when air containing water vapor enters the system, or alternatively when the system is subjected to excessive heat and the refrigerant drier releases retained water. When this happens, acids created by the reaction of the air, water, refrigerant and oil cause iron components in the system to become plated with copper, which can cause bearing failure due to copper plating. In refrigerant systems, the acid content of the oil, the moisture content and the copper concentration level need to be regularly monitored in order to indicate incipient problems.

In Figures 5–7, the Total Acid Number of the Elevators I, II and III is presented respectively. In all three lifts, the fluid had the greater TAN when the sampling period began. For Elevator I, the conclusion which results from the sulfur measurement, which is that fresh hydraulic oil was added in November 2012 and in March 2013, was confirmed. The same happened in Elevators II and III. In Elevator III, the TAN was raised again in May 2013 which means that the working conditions of the lift must be examined carefully in order to avoid severe damage in its engine, pump or stroke.

Figure 5. Total Acid Number of Elevator I.

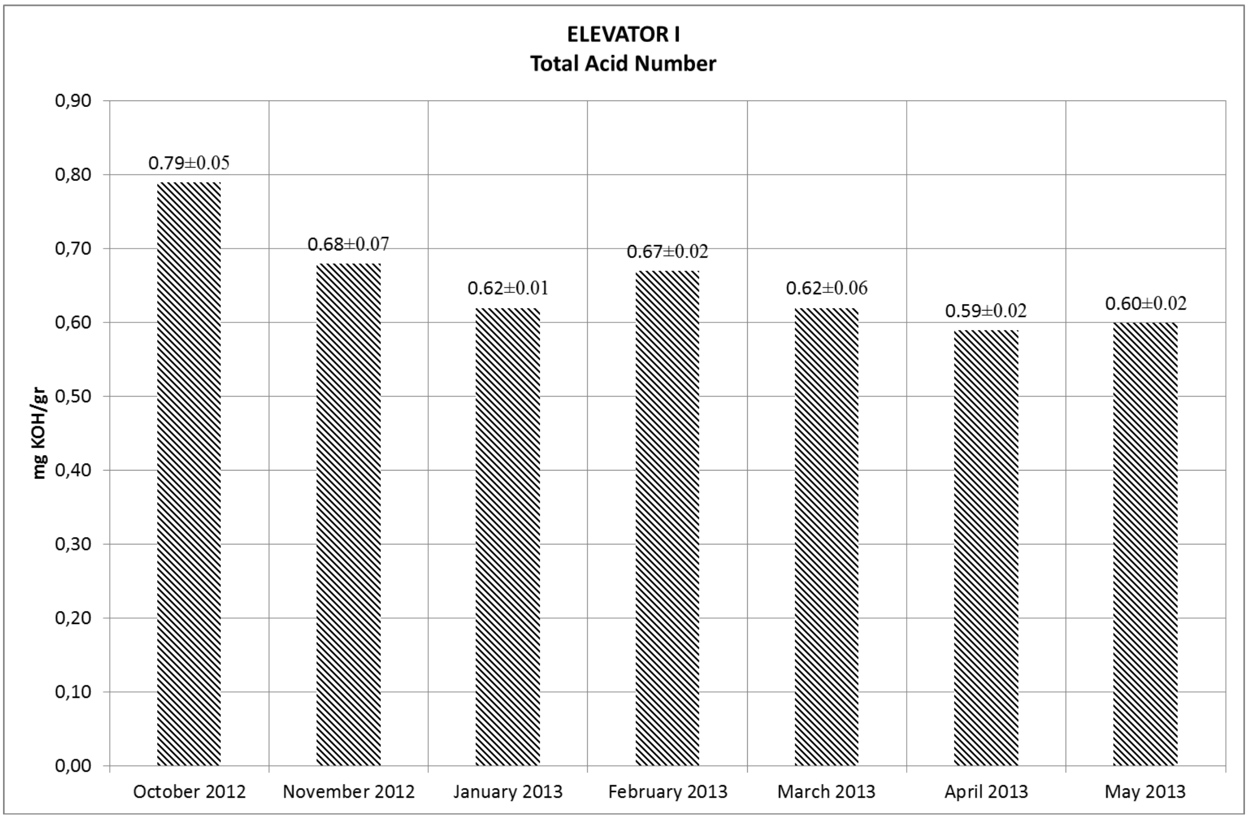


Figure 6. Total Acid Number of Elevator II.

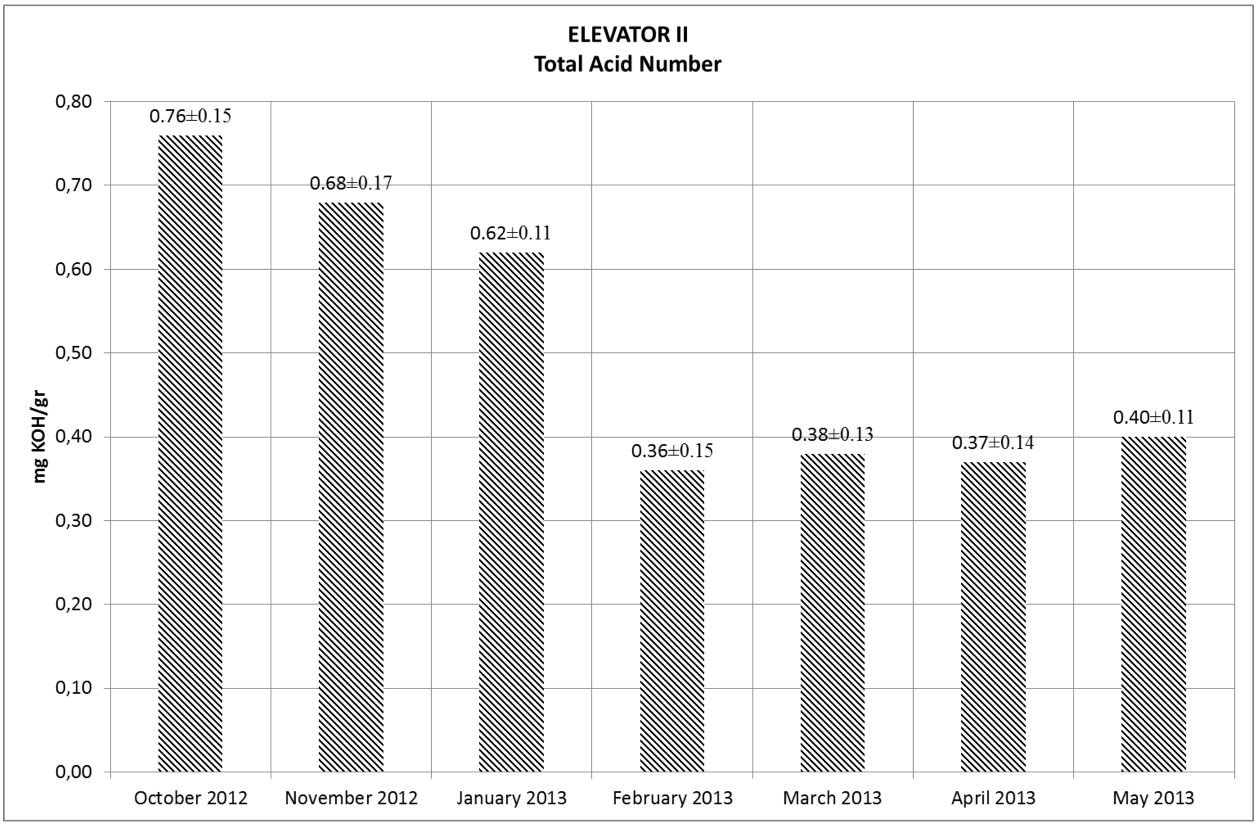
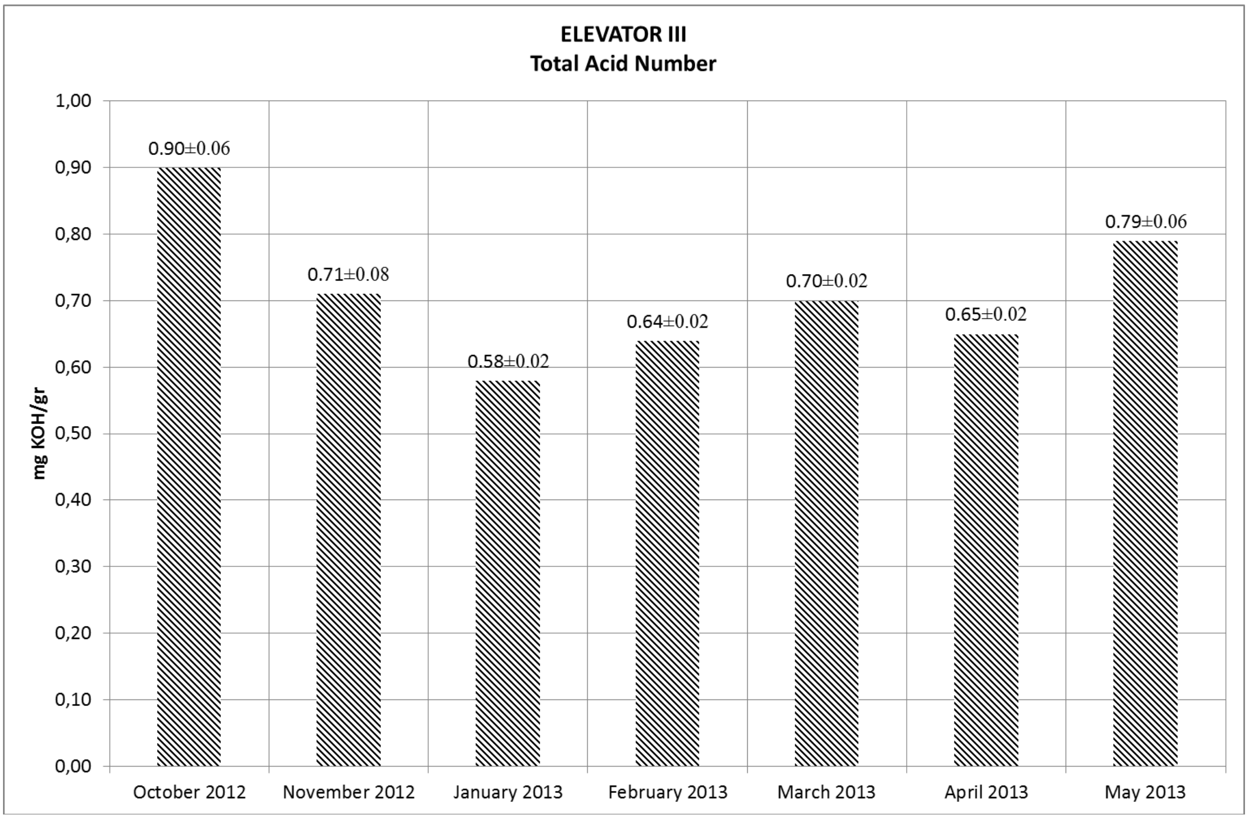


Figure 7. Total Acid Number of Elevator III.



3.4. Metals

During this study, phosphorous, zinc, chlorine and calcium concentration were measured. The results are presented in Figures 8–10 for the Elevators I, II and III respectively. The hydraulic oils have additives which contain phosphorous and zinc. The results of the October 2012 sampling were taken as a base in order to evaluate the alterations. It is well known that metals and especially the wear metals are the result of corrosive wear due to water and acids but also abrasive wear due to surface roughness metal contact which is leading to welding. On the other hand, the wear metals promote fluid oxidation, cause abrasive wear and may stabilize the formation of oil-water emulsions formed by water contaminants. Wear metals may affect the useful life of hydraulic oil.

In Elevator I, there is an increase in the amount of calcium and chlorine. This increase repeated and after the addition of fresh oil on March 2013. There is an increase in the concentration of calcium. This element can be provided into the oil from the existence of atmospheric dust or airborne dirt, hard water or salt water. Indeed, the results of the visual examination showed that the elevator well-hole was very dirty. Furthermore, the existence of chlorine is very critical since it attacks the metals leading to corrosion. The chlorine is mainly from the solvents which were used for normal cleaning or flushing operations. The source of chlorine could also be the chlorinated alkanes which were used as anti-wear and anti-stick additives.

The same observations were occurred and for the Elevator II.

Figure 8. Metals in Elevator I.

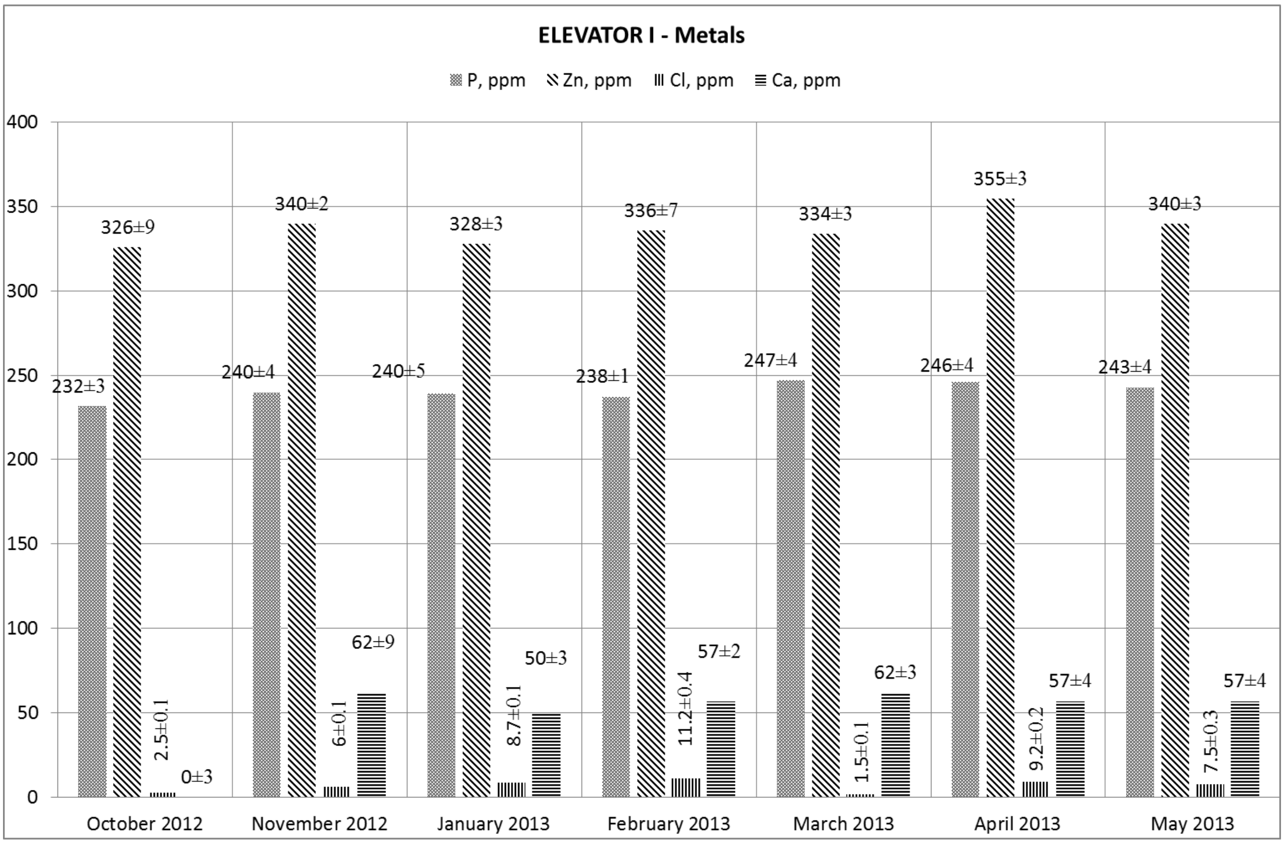


Figure 9. Metals in Elevator II.

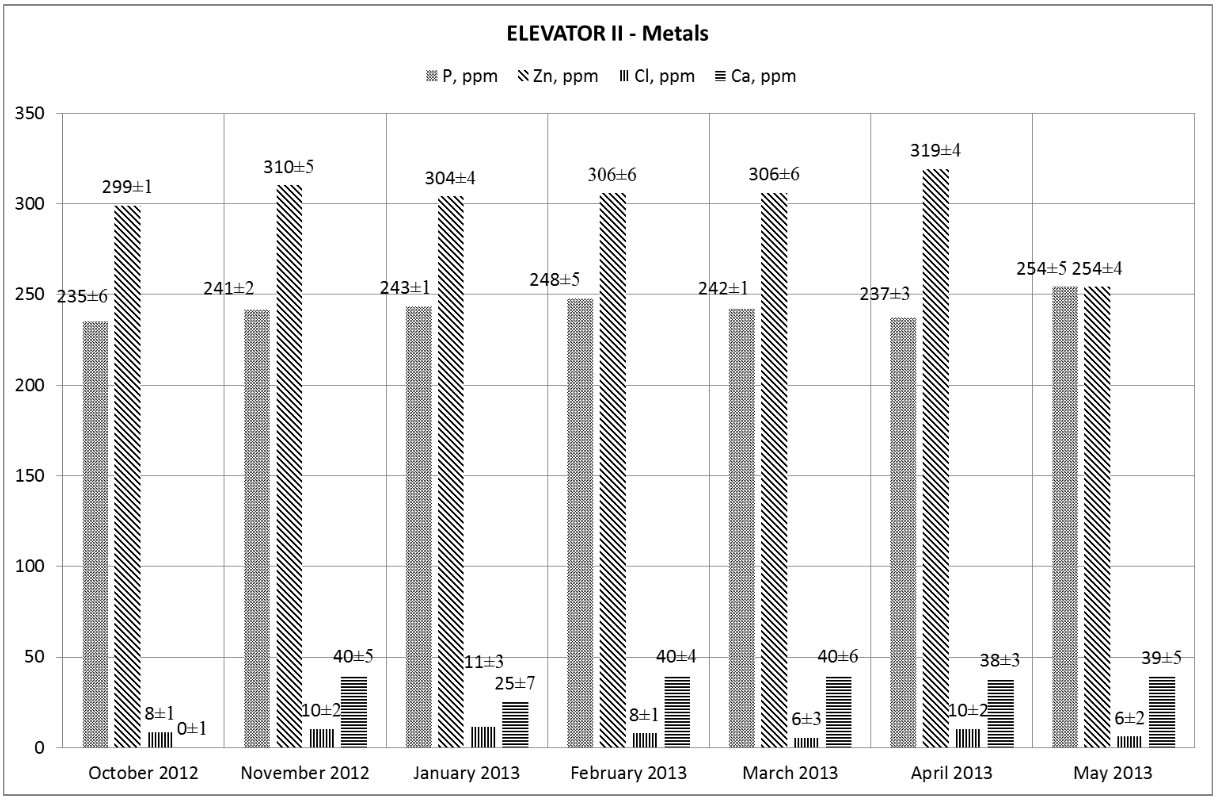
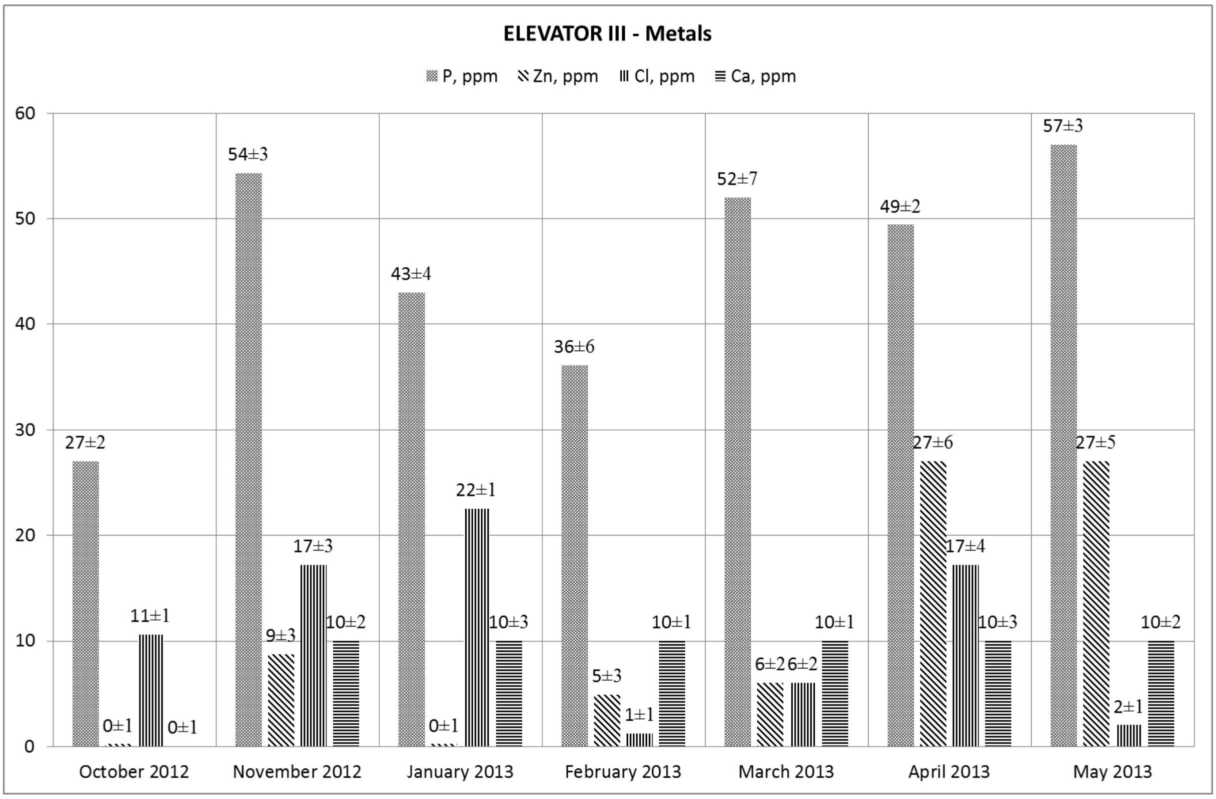


Figure 10. Metals in Elevator III.



In the Elevator III, it is clear that the oil that was used is different than the working oils in the first two elevators. Through the sampling period, the zinc concentration has increased significantly. As explained before, the results of the October 2012 measurement is the basis of the comparative analysis. The increase of zinc means that the working environment is corrosive. Additionally, it reveals the existence of assembly debris and wear. The amount of chlorine measured was the greater between the three elevators. The amount of calcium shows an increase too. This increase means that the fluid is working on a dirty environment.

4. Conclusions

The examination of elevators' hydraulic engines' fatigue through the analysis of their hydraulic fluid has been investigated. The results can be summarized as follows.

All hydraulic fluids examined were not complying with the specification of the engine manufacturer. More specifically, for two of the elevators, the hydraulic fluid which was used has viscosity that does not conform to the classifications' viscosity grade range. Additionally, one elevator was working with different grade of hydraulic fluid from the one proposed by the engine manufacturer.

The elemental analysis of sulfur levels in the hydraulic fluid shows the maintenance intervals in the operation of the elevators.

The analysis of zinc, phosphorous, chlorine and calcium, verifies that the oil which was used in one elevator is different from the oil used to the other two. Additionally, it reveals a significant wear to all the elevators as a result of the working environment conditions.

The analysis of the hydraulic fluid can be included in the testing procedures which examine the safety of lifts.

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Conflicts of Interest

The author declares no conflict of interest.

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